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TRIP REPORT
EPRI WORKSHOP: OPTICAL SENSING IN UTILITY APPLICATIONS
MAY 14-15, 1991; SAN FRANCISCO, CALIFORNIA

L. Mannik

A paper describing the performance of the generator rotor temperature sensor being tested at Nanticoke TGS was presented at an EPRI-sponsored workshop dealing with optical sensing applications of interest to electrical utilities. Among other topics covered at this meeting were fiber optic sensors of various types, including physical (temperature, strain), electrical (current, voltage) and chemical. As a result of this meeting, a users group was formed to bring together manufacturer and utility representatives for periodic information exchange. Prior to the workshop, a visit was made to Luxtron to discuss the applicability of their latest technology to reducing the cost of the rotor temperature sensor.

1. BACKGROUND

Recognizing that numerous potential opportunities exist for applying optical sensors to utility systems, the Electric Power Research Institute (EPRI) organized a workshop entitled Optical Sensing in Utility Applications aimed at identifying utility needs and manufacturer capabilities in this area. Reports on utility experience with optical sensors were solicited, which resulted in our being invited to present a paper on the development of the generator rotor temperature sensor. This technology is nearing the commercialization stage after several years of testing in the laboratory and in field trials at Nanticoke TGS/1/. Another purpose of this workshop was to explore the interest in forming a users group to provide a forum for regular exchange of information between utilities and suppliers of optical sensing equipment.

An EPRI report on the proceedings will be published in six months, but in the meantime, detailed write-ups of most of the presentations are available from the author.

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One company that would be involved in any commercialization of the rotor temperature sensor is Luxtron. Not only do they hold many of the fundamental patents in phosphor thermometry, but they have recently developed a third generation instrument which, if adaptable to our sensor, could dramatically reduce the cost and thereby expand the market for a rotor temperature monitor. Since Luxtron is located near San Francisco, I took the opportunity of visiting their facility and meeting with their technical personnel.

This report will begin by describing the various types of optical sensors covered at the workshop, which attracted 80 participants, including a handful of international attendees. This will be followed by a discussion of EPRI's viewpoint and utility needs, as expressed in both the formal presentations and in informal discussions. The workshop culminated in the establishment of an Optical Sensing Manufacturers/Utilities Group (OPSM/UG), whose aims and structure are outlined.

2.0 TYPES OF OPTICAL SENSORS

2.1 Temperature

My presentation on the generator rotor temperature sensor, summarized in the Appendix, elicited many questions, mostly related to technical details. It also stimulated interest on the part of Michael Benson of PG&E (Pacific Gas & Electric) in using this technology to measure the surface temperature of synchronous condensers. The expected temperatures in this application (~100°C) are well within the range of phosphor thermometry and there should be little difficulty in installing fibers in these machines. I should note that recently we have also had enquiries about this technology from CEGB and Westinghouse concerning its use in the temperature measurement of rotor wedges and retaining rings, respectively.

Ken Wickersheim of Luxtron outlined their latest fiber optic point temperature probe as it relates to the monitoring of winding temperatures in power transformers. PG&E will be using this technology to instrument a number of transformers for predictive loading purposes. A European manufacturer (Smits) has begun to use these sensors in its own factory testing of large transformers and is willing to leave the sensors in place for use by the utility customer. These sensors use a new type of phosphor which is excitable by visible light from an LED, which means that the costs of both the light source and delivery fiber can be substantially reduced compared to the current technology, which uses ultraviolet excitation. In my discussions with Luxtron it was evident that for us to use this new phosphor with its 500 μs decay time, it would be necessary to install a second collection fiber in an adjacent stator cooling channel. An alternative approach, which we will explore with Luxtron, is the use of a second type of phosphor whose decay time was too short (100 μs) for their purposes, but which may be appropriate for our application.

For temperatures above 400°C, there is enough black body radiation emitted by an object that optical pyrometry makes sense. An English company, Land Infrared, has refined this technique to measure the temperature of the turbine blades in aircraft engines. Knowledge of blade

temperatures is a critical issue, especially for high performance fighter aircraft engines. Over the past three years, they have adapted this technology to power generation gas turbines and have demonstrated its capability in field trials at three US utilities. The software is designed to display the blade number and measured temperature over the range 600 to 1100°C. Initial problems of pyrometer damage due to failed cooling have been overcome by using an optical fiber to move the instrument far enough away that cooling is not required.

In addition to these point temperature probes, there has been progress in the development of distributed temperature sensors, in which optical radar techniques are used to determine the location and magnitude of hot spots along the length of an optical fiber, which is attached to or embedded in the component of interest. There are at least two competing technologies. One of these, which uses the backscattered light from a special cladding material applied to the fiber, has been developed at Battelle Columbus Laboratories with EPRI support; initial field trials of this sensor on a switchgear circuit breaker were presented at the workshop. All of the performance goals for this sensor have been met (range: 20-150°C, length: 20 m, resolution: 10 cm), except for temperature accuracy, which is ±5°C rather than ±2°C. The present cost of this instrumentation is high because of the need for a special OTDR (Optical Time Domain Refloctometer) priced at $30 K. Other utility applications envisaged for this technology include the monitoring of generators, motors, transformers and transmission lines. For the latter application, an alternative technology commercialized by a British company (York), which uses Raman backscattering from the fiber core, may be more suitable, since it lends itself to longer lengths (2 km), albeit with lower resolution (1 m). Unfortunately, York chose not to exhibit at the workshop, but I did obtain information on the product from the American distributor, who indicated that the resolution would be down to 10 cm by the end of the year and the maximum length could soon reach 100 km. One of the application areas targeted by York is the optimization of power loading in electricity distribution networks.

A consulting company, G2 Systems, has applied distributed fiber temperature sensing to the monitoring of a variety of fossil-fuel power plant applications, such as headers, water walls, manifolds, steam pipelines and support structures. These sensors are designed to measure pressure and deflection/strain as well as temperature. Initial trials will be performed at Southern California Edison.

2.2 Electrical

Several papers at the workshop dealt with the development of optical fiber sensors to measure voltage, current or fields. Good results were reported from a year-long field trial by Florida Power & Light/Square D of a new high accuracy optical current transducer system, which measures the currents flowing through a 230 kV substation transmission line terminal. Advantages over a conventional current transformer are smaller footprint, lower weight and improved safety because of the oil-free insulation system.

Centerior Energy in Ohio described plans to test a low cost fiber optic sensor for fault detection on the 138 kV input lines of a distribution substation that will be operational in 1992. A key point made in this presentation was that, by resisting the temptation to over-specify the accuracy

of the sensor, the company was able to obtain a device that met its requirements at a reasonable cost.

Several international representatives made contributions to this session. The Technical University of Denmark described the construction and testing of a 132 kV SF_6 insulated electrooptic instrument transformer. The high voltage potential is divided by compressed gas capacitors and the voltage is measured by an electrooptic sensor connected in parallel with the lower voltage capacitor. There were two brief reports from Italy. One, from CESI, described compact current and voltage sensors developed as part of a European Economic Community program dealing with Optical Fiber Electrical Industry Applications (OFELIA). The other, from Pirelli, featured a small (30 mm long, 7 mm diameter) electric field probe targeted at high voltage cable applications.

2.3 Chemical

Two papers at the workshop dealt with fiber optic chemical sensors for utility applications. These hold the promise of measuring specific substances or classes of substances in the ppm and ppb range, as detailed in a project performed by FiberChem for PSE&G (Public Service Electric & Gas) in New Jersey. The initial focus has been on the detection of hydrocarbons by replacing a portion of the fiber's cladding with a sensing material which reacts with the chemical, thereby changing the light transmission of the fiber. Two types of sensors are available, a continuous monitoring system for permanent installation and a hand-held "chemical dip stick" which is battery operated. With a 7.6 cm length of sensor material, chemicals such as xylene and kerosene have been detected at the ppm level. This sensor has been developed in response to US Environmental Protection Agency requirements for the monitoring of underground storage tanks, storm drains and hazardous waste sites.

A two year old company in Washington state, Research International, has identified a need for utilities to have instrumentation to monitor chemical equilibria, detect decomposition products and sense trace contaminants in diverse media. These needs are driven by increased public concern for the environment and by a utility need to maximize equipment life. As a result, this company has come out with a measurement system consisting of an optoelectronics interface integrated onto a PC card, fiber optic sensors to interface with the card and a software package for data acquisition and display. The system provides remote monitoring of hydrogen, humidity, pH, aromatic hydrocarbons or temperature. A different fiber optic sensor would be used in each case, based on the principle that the spectral reflectance of the material in the active volume at the tip of the fiber changes with variations in the sensed parameter. The paper presented at the workshop described the pH sensor, which is aimed at corrosion control in the 300°C water flowing through the secondary loop of a pressurized water reactor. The active end of the optical fiber contains an indicator whose absorbance at 650 nm changes with pH; this change is monitored by measuring the intensity of light from an LED which is passed twice through the chemical indicator using a mirror at the end of the fiber. A chromophore that is stable to 200°C has been found. While this is below the temperature required for this particular application, it is high enough to be useful in other parts of the reactor.

3. EPRI OVERVIEW/UTILITY NEEDS

Jan Stein, an EPRI project manager and co-chairman of the workshop, opened the proceedings with a keynote address, in which he emphasized the need for better cooperation between utilities and sensor manufacturers to overcome the resistance that exists in many utilities to this type of new technology. He advised manufacturers to focus on lowering the cost of sensors and to simplify maintenance and installation requirements. He also cautioned against overselling the capabilities of these sensors. If the users group described below functions as designed, it could go a long way to overcoming some of the current difficulties in transferring this technology to the more than 1000 utilities in North America.

Research on fiber optic sensors has been under way at EPRI for approximately 10 years. An earlier workshop in 1988/2/ identified many potentially beneficial applications, several of which are currently under development. These were summarized by Walt Esselman, a consultant to EPRI. Aside from temperature measurement, there are projects investigating the use of optical fibers in leak detection (boronated water in nuclear power plants), process chemistry (pH and other chemical sensors), mechanical sensing (point and distributed strain sensors) and electrical measurements (electric field sensor). Esselman stressed the need to explore the limitations of fibers in utility applications, with regard to factors such as the temperature limit and radiation damage. A program sponsored at Ohio State University is determining the effect of dose and dose rate on commercially available fibers. An exciting prospect is that the fogging induced by radiation exposure could be reversed by heating the fiber or by shooting a high energy laser pulse through it. Looking to the future, Esselman highlighted the field of microsensing with its potential for producing miniature low-cost sensors, in much the same way that computer chips are currently manufactured. The key then would be to identify the applications that can benefit from multiple low-cost sensors.

In an informal presentation, Joe Weiss, a project manager in EPRI's Nuclear Plant Operations and Maintenance Program, gave his views on current needs. He emphasized the importance of keeping nuclear power plants running with a high capacity factor, because of the high cost of replacement power ($500K/day). He gave an example of a technical problem, fouling in the feedwater flow circuit, which requires derating of reactors at a penalty of 5 to 15 MW every day. In this case, replacement of Venturi nozzles by laser Doppler velocimeters would be attractive and has been explored, but there are apparently difficulties with optical access and with the accuracy of the technique. He also echoed Walt Esselman in emphasizing the need for research on the effect of high temperatures and radiation fields on fiber performance. Among the specific projects that he mentioned was one on the measurement of strain on pump shafts at our Nuclear Process Components Test Facility. Phosphor fluorescence techniques may be applicable to this investigation.

A panel discussion at the end of the workshop gave an opportunity for the host utility (PG&E) to present its perspective on the needs for optical sensing. The key issues in the decision to apply any new technology are cost, reliability, performance and integration into the existing system. Among the specific needs that optical sensors could address are the monitoring of transformer and transmission line temperatures, the analysis of dissolved gases in transformer oil

and the measurement of mechanical properties such as strain in various components. The most successful projects are those with a clearly identified utility sponsor. For example, PG&E is having 50 of Luxtron's new generation of fiber optic temperature probes installed in its transformers. This utility has taken a business-driven decision to load certain assets beyond the nameplate capability, using advanced diagnostics to lower the risk, but with the understanding that outages of up to 24 hours will be tolerated. They also regularly perform autopsies and rebuilds of failed equipment.

4. FORMATION OF USERS GROUP

Emile Hyman of PSE&G has for several years been espousing the benefits of an optical sensing users group to bring together utility and manufacturer representatives to exchange information and generate ideas. His model for such an organization is the Utility/Manufacturers Robot Users Group (U/M RUG), which was established in 1985 by a colleague of his, and which now numbers over 200 members interested in robotics technologies for utility applications. Members take turns hosting one-day meetings three times a year, featuring informal presentations, demonstrations and a chance to brainstorm new ideas. Although not every member attends every meeting, all members receive copies of the minutes and materials presented.

An open discussion of this concept at the workshop produced unanimous support for the formation of such a group for optical sensing. More than 50 of the 80 attendees had signed up by the end of the workshop, including the author. The discussion period turned into a rather entertaining, no holds barred session, with suppliers attacking the utilities for being too risk averse and the utility members complaining that the manufacturers need to do better market research before developing new products. One of the more colourful quotes was from a supplier with more than 12 years experience in the sensor business, who told the utility representatives, "you guys are the biggest collection of blockheads I've ever come across". Clearly there is a need for improved communications, which this forum is designed to provide. The first meeting is scheduled for this fall.

5. SUMMARY

A workshop co-sponsored by EPRI on opportunities for optical sensing in utility applications featured many interesting presentations on fiber optic sensors for temperature, as well as mechanical, electrical and chemical parameters. Included in the program was a paper on the generator rotor temperature monitor developed by Research Division and tested at Nanticoke TGS. An important outcome of this meeting was the formation of an Optical Sensing Manufacturers/Utilities Group (OPSM/UG) to improve the information exchange in this field.

Approved:

A.F. Baljet
Manager
Electrical Research Dept

Submitted:

L. Mannik
Senior Physicist
Science Section
Electrical Research Dept

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APPENDIX

AN ON-LINE FIBER-OPTIC ROTOR TEMPERATURE MONITOR FOR LARGE TURBOGENERATORS

L. Mannik
S.K. Brown
Ontario Hydro Research Division
800 Kipling Avenue
Toronto, Ontario, M8Z 5S4
Canada

S.R. Campbell
Iris Power Engineering
1550 Meyerside Drive
Mississauga, Ontario, L5T 1V4
Canada

ABSTRACT

An optical technique has been developed for the on-line monitoring of rotor surface temperatures in turbogenerators. The method is based on the measurement of the decay time of the ultraviolet-laser-stimulated fluorescence produced by phosphors painted on the surface of the rotor during a scheduled outage. Optical fibers installed in stator cooling channels are used for light delivery and collection. Field tests on an operating 500-MW generator have yielded temperatures from 41 to 73°C with a spatial resolution of 4 mm and an accuracy of ±2°C. Efforts are underway to improve the durability of the paint, which lasted two years in the first installation.

INTRODUCTION

The integrity of insulation in a rotating machine is critical to its proper operation. Progressive breakdown of the rotor insulation will force a machine outage and may result in extensive winding and iron damage. Although catastrophic insulation failures are infrequent, their occurrence represents a significant cost for large generators, particularly in terms of replacement power costs. Therefore, methodology to give warning of problems at an early stage would be of great value to the utility industry.

There is at present no means available for the direct measurement of rotor winding temperatures. Although an average rotor temperature can be inferred from measuring the rotor winding resistance, hot spots from blocked cooling, imbalanced cooling and shorted turns are difficult to detect. Therefore, as part of an EPRI sponsored project on Motor and Generator Insulation Life Estimation (RP 2577-1), effort has been directed at developing a method of measuring localized rotor temperatures on-line.

PRINCIPLE OF OPERATION

The method described here, named the Passive Rotor Temperature Sensor (PRTS) because there are no active components on the rotor, is based on the fact that certain phosphors, after excitation by ultraviolet light, emit a visible fluorescence whose decay time is directly related to the temperature of the phosphor. By combining the phosphor with a suitable binder and painting a surface with a thin coating of the mixture, it is possible to achieve remote, non-contact thermometry of the surface. In the application of this technique to rotor temperature monitoring, a commercially available compact nitrogen laser is used as the source of ultraviolet light and optical fibers are used for light delivery and collection.

The main advantage of this sensor is its passive nature - a chemically and electromagnetically inert coating is painted on the rotor at selected regions. This provides a broad coverage of localized temperatures, limited only by geometrical factors which determine the areas on the rotor that can be accessed by optical fibers threaded through the stator.

LABORATORY TESTING OF PROTOTYPE

Initial investigation of the PRTS system was performed using a 30 cm disc rotating at 1725 rpm to simulate a turbine generator rotor. The phosphor was applied to the disc near the outer edge. Figure 1 is a block diagram of the prototype rotor temperature sensor which was designed and constructed. A thin (75 μm) layer of a 2:1 mixture by weight of binder (silicone resin) and phosphor powder (Y_2O_2S:1%Eu) was the temperature sensitive material initially investigated. The excitation source was a compact nitrogen laser (Laser Science Model VSL-337ND) which produced >150 μJ pulses of ultraviolet output at 337 nm at a repetition rate of up to 20 Hz. A 25-cm focal length lens focused the output into an optical fiber (15 m length of 600 μm core diameter plastic-clad silica). A 5.8-cm focal length lens focused the ultraviolet energy emerging from the fiber onto a 4-mm diameter section of the phosphor-coated surface 20 cm away from the end of the fiber. A second identical fiber was used to collect the visible emission from the phosphor. The output from the fiber passed through a 514 nm filter and was detected with a photomultiplier.

Data collection and analysis were performed with a microcontroller-based system designed and assembled in-house. An 8-bit 10 MHz A/D converter transforms the signal from the photomultiplier into digital form with a time resolution of 100 ns. The digital signal is fed into an Intel MCS-96 microcontroller, a powerful single chip computer which performs all the calculations on the data and all input/output including user interface and data storage. Included on the chip are various input/output ports and two 16-bit counter/timers. One of the timers is used to synchronize the triggering of the laser to the rotation of the disc so that during a temperature measurement the laser acts as a stroboscope viewing the same phosphor spot on the disc. A reference signal for the synchronization is provided by a photodiode viewing a piece of tape attached to the rear of the disc. An RS232 port connects the microcontroller to an external computer, which is used to output data and to coordinate the temperature monitoring program, ie which locations on the rotor are interrogated and in which sequence.

There are two possible methods of extracting a decay time from the phosphor data. For each laser pulse a record of many samples (eg, 1000) taken every 100 ns is stored in memory. In one approach this is repeated for many (up to 256) laser pulses and the results are averaged to yield a low noise waveform from which a decay time is extracted. Another option is to take a record of a single laser pulse and to use curve fitting techniques to deduce a decay time for each set of samples. The first approach would be more accurate but would require a longer time for data collection and would, therefore, result in earlier replacement of the laser cartridge, whose lifetime is specified as 10^7 shots. In either case, the temperature is deduced from the decay time by means of a look-up table consisting of stored calibration data.

In taking the PRTS design from the laboratory to the field, it was necessary to consider the environment inside the generator. This involved selection of phosphor, binder and optical fibers for this application, as well as testing of the effect of magnetic field and oil on the operation of the sensor. Details are presented in earlier publications (1,2). One result of these tests was that the delivery fiber was chosen to be an all silica fiber with nylon jacket, while the collection fiber was a silica core, hard silicone polymer cladding with a Teflon jacket. It was also necessary to select suitable lenses to focus the ultraviolet light onto the phosphor, given the restricted space available inside the generator. Laboratory testing established the optimum focal length (20 mm) and the separation of the front of the lens from the end of the delivery fiber (21 mm), to yield a 4 mm spot at a separation of 7.6 cm, corresponding to the generator air gap.

FIELD TESTING

For the initial field installation, the feedthrough to bring the fibers through the generator housing was constructed by a commercial supplier based on our modifications to their basic design. The 1-inch diameter feedthrough encased all the fibers in epoxy, with two O-rings providing a seal against the hydrogen gas inside the generator. Prior to installation the feedthrough was pressure tested under 4 atm of helium and no leakage was detected. Also the optical transmission of the fibers was measured to ensure that they had not been damaged during fabrication of the feedthrough. For the second installation there was a series of difficulties in getting feedthroughs assembled properly by the supplier. As a result we fabricated the feedthroughs in our laboratories. Stainless steel fittings were machined and potted with a special epoxy designed for fiber applications. The metal surface was cleaned with an acid mixture prior to potting and the Teflon-jacketed fibers were pre-treated with an etching compound. The resulting feedthroughs were found to be leak-tight under helium pressure testing.

Two installations of the PRTS were made on 540 MW turbine generators in Ontario Hydro (Figure 3). The first of these occurred in Unit 5 at Nanticoke Thermal Generating Station in April 1988. Four sets of fibers were to be used to measure the temperature distribution around the rotor at four locations along its length. However, in the course of installing the fibers in the generator, two fiber sets were broken and one was damaged. The fibers were routed from the feedthrough and through stator radial cooling vents using two types of conduit (Neoprene and Teflon). Small (6.3 mm diameter) fused silica lenses were epoxied into the end of the Teflon tubing used to guide the fibers from the back of the stator core to the bore. Prior to installation,

the tops of the lenses were ground down to provide space for the collection fibers. After the installation of the lenses, we measured the transmitted laser energy inside the stator. At the location with undamaged fibers the transmission was 25% while at the damaged location it was only 4%.

Combinations of Y_2O_2S and Gd_2O_2S phosphors and two silicone resin binders were mixed in a 2:1 ratio by weight of resin: phosphor and painted in 5-cm wide bands at each of the selected locations along the rotor. The thickness of the paint was estimated to be 75 to 100 μm. One wedge in each band was left blank to serve as a convenient reference point to orient ourselves on the rotor circumference once time decay measurements were initiated. A second wedge was painted with two phosphor sections and one blank section to enable us to pinpoint where the phosphor excitation was occurring along the width of the band. The synchronization signal was provided by a photodiode viewing a black strip spray painted on the shaft at the slip ring end.

During the initial field tests of the PRTS, problems were encountered with the temperature calibration of the two phosphors. Laboratory testing established that the difficulty arose from the fact that the phosphor decay time was dependent on the energy of the exciting ultraviolet laser beam. Since the laser energy reaching the phosphor in a generator is dependent on a host of unpredictable factors such as oil absorption and fiber transmission, the result is a greater uncertainty in the temperature as determined from the phosphor decay time. In an effort to overcome this problem, a different phosphor (La_2O_2S:Eu) was investigated which displayed no such energy dependence in earlier measurements at Oak Ridge National Laboratory (3). Temperature calibration of this phosphor (Figure 2) showed no dependence of decay time on laser energy up to the maximum usable temperature (90°C). This should accommodate most temperature excursions of interest in an operating generator, while higher temperatures could be estimated at reduced accuracy (± 5°C rather than ± 2°C) using either Y_2O_2S:Eu or Gd_2O_2S:Eu phosphors.

The second field installation, at Nanticoke Unit 4 in June 1989, was designed to avoid the difficulties in fiber installation as well as the phosphor calibration problems described above. In this case there were two test locations and each fiber pair had its own feedthrough and conduit to prevent tangling of the fibers inside the generator. Each conduit was a continuous piece of Teflon tube running from the bulkhead to the back of the core. This tubing was flexible yet strong enough not to be crushed if stepped on. The conduit from the back of the core to the bore was 6.4 mm ID Teflon tubing as before. The fibers were installed only after the conduits were installed and secured. To avoid having excess fiber length coiled up at the back of the core, the fibers were cut to length and polished prior to installation.

In the Unit 4 installation, the two bands were painted with the three phosphors mixed in a 1:1 ratio with two types of silicone resin. No fibers were broken during the second installation. Measurements inside the stator demonstrated 43% ultraviolet laser transmission at the one location and 38% at the other. Each installation required about 2 days for 3 persons to complete.

RESULTS OF FIELD EVALUATION

First Installation

A series of measurements made during the start-up of Unit 5 confirmed laboratory findings that the magnetic field does not influence the phosphor decay time. Monitoring the fluorescence signal over a period of time demonstrated a gradual reduction in magnitude, which was attributed to the presence of oil inside the generator. This was supported by the observation of a strong fluorescence spike at the beginning of the phosphor decay time signals.

In spite of the difficulties with the temperature calibration described above, it was possible to extract some temperature information using Gd_2O_2S phosphor data from the band with the undamaged delivery fiber. One interesting result was that there was a significant difference between rotor wedge temperatures measured for wedges with and without windings underneath. The former yielded temperatures of 50 to 55 C while the latter were at 44 C, with the generator operating at 540 MW. While the absolute temperatures are open to question because of the calibration problems, the trend in the two sets of temperatures followed the expected course.

Second Installation

Following start-up of Unit 4, phosphor decay time measurements were initiated. Initially, reasonable signals were observed at both locations but soon after the signal from one of the bands dropped off dramatically. Our initial conclusion was that the lens had been dislodged, but in retrospect, this was probably an indication of paint durability problems discussed below.

We also experienced difficulty with the triggering of the signal, due to a degradation in the synchronization signal caused by the timing mark on the shaft being worn away by a dust seal during shaft expansion/contraction resulting from thermal cycling. In spite of this, we were able to measure the temperature at 24 locations around the circumference of the rotor using the La_2O_2S:Eu phosphor. The results are shown in Figure 4. The temperatures are estimated to be accurate to ± 2 C and the spatial resolution is 4 mm. The generator was operating at 500 MW and the average temperature as determined from the copper resistance was 55 C. As in the first installation the higher temperatures measured tended to be in locations with field windings underneath. It is worth noting from Figure 4 that, in general, temperatures measured at symmetrically placed points around the circumference of the generator agree to within a few degrees. The only exceptions are the pairs 41/56 C and 50/63 C.

CURRENT STATUS

The difficulty with the triggering has been solved by using an electrical signal from one of the proximity sensors located on the rotor shaft between the generator and the turbine. Approximately two years after the initial field installation, we had the opportunity of viewing the condition of the phosphor paint during a rotor outage. It was evident that the paint had survived well at the end of the rotor, but the bands in the middle of the rotor were barely visible. On

close examination, it appeared that the problem was one of abrasion rather than adhesion. The main difference in the generator environment at these two locations is the high speed, turbulent flow of hydrogen cooling gas which exits the rotor near the center. Since this gas contains various particulates of oil and dust, it can act as a sandblaster to remove the paint from the central region of the rotor. This problem would have been accentuated in the second field test, where we used a higher phosphor concentration in an effort to increase the fluorescence signal. This accounts for the loss of signal after less than 1 year of operation in this installation.

We therefore undertook an investigation of alternative binders which would have better abrasion resistance. The results of this study are summarized in Table 1. In addition to the silicone resin that was used in all our previous trials, we obtained samples of polyurethane and acrylic materials and tested all three classes of compounds in an abrasion test facility. The results indicate that either of these alternative binders would perform better in an abrasive environment than the silicone resin. While the fluorescence signal measured with this particular polyurethane was approximately half that of the other two binders, it may be possible to find other binders in this class which have better ultraviolet transmission properties with equally good abrasion resistance. These studies, which will include accelerated thermal aging tests, are continuing.

TABLE 1

TESTING OF BINDERS FOR PHOSPHOR PAINT

MATERIAL	ABRASION RESISTANCE (s/mm)	FLUORESCENCE SIGNAL (arb. units)
Silicone	700	122
Acrylic	2300	166
Polyurethane	5000	72

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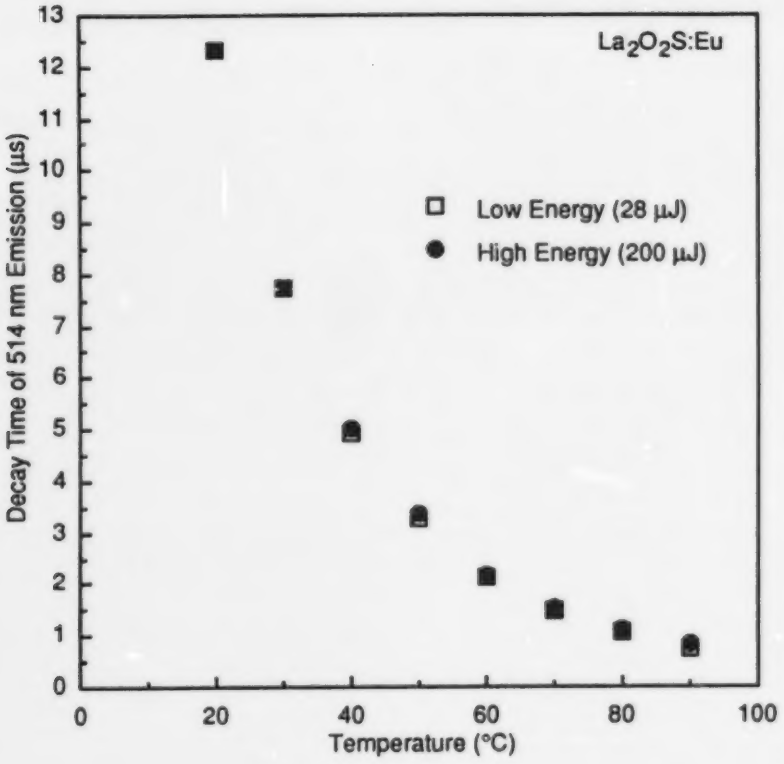

FIGURE 1

TEMPERATURE DEPENDENCE OF 514 nm DECAY TIME FOR La_2O_2S:Eu PHOSPHOR UNDER LOW AND HIGH ENERGY ULTRAVIOLET LASER EXCITATION

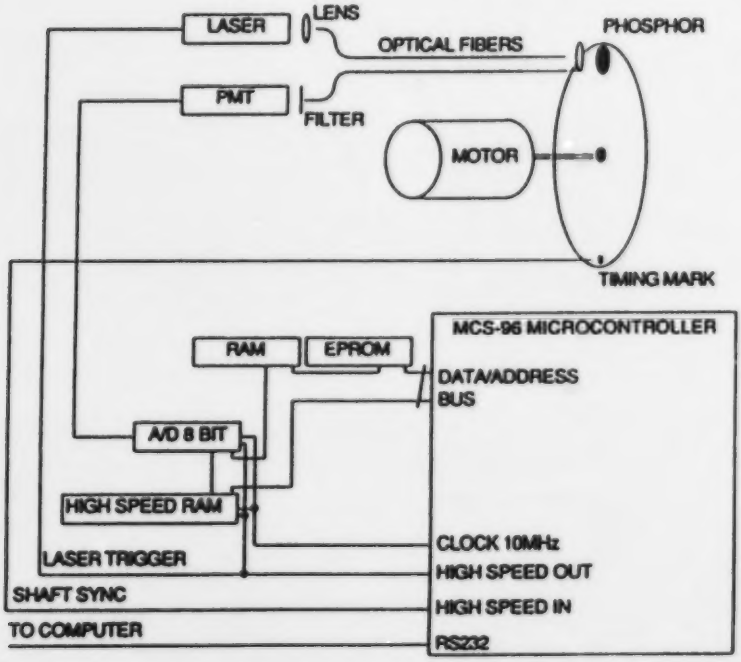

FIGURE 2

GENERATOR ROTOR TEMPERATURE SENSOR PROTOTYPE BLOCK DIAGRAM

179034-F30-RD

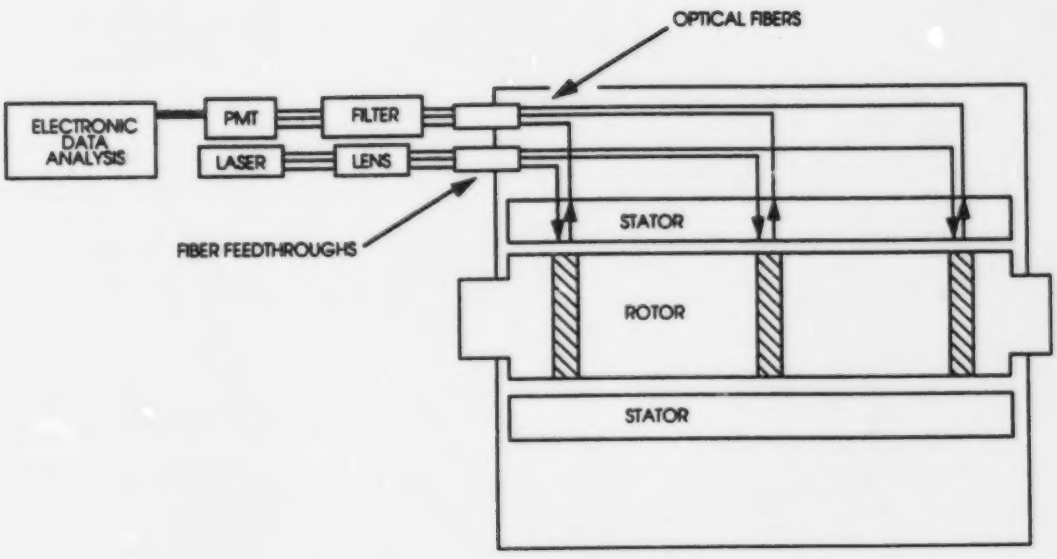

FIGURE 3

SCHEMATIC DIAGRAM OF FIELD INSTALLATION OF THE ROTOR TEMPERATURE MONITOR ON A 540 MW GENERATOR

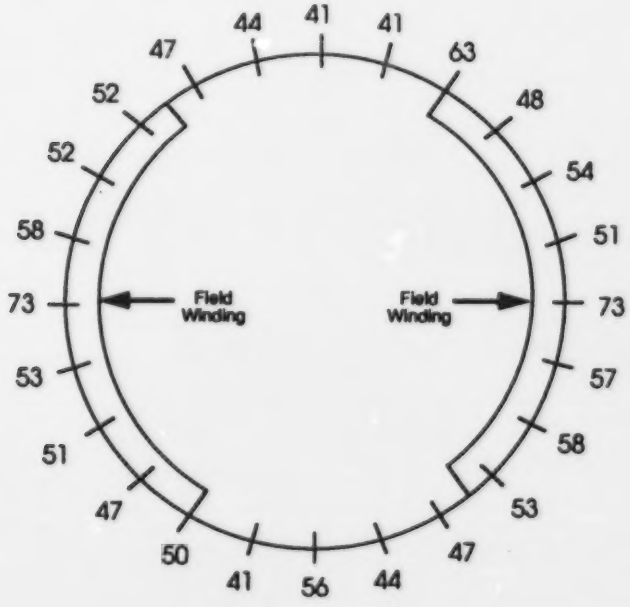

FIGURE 4

TEMPERATURE IN C MEASURED AROUND THE SURFACE OF THE GENERATOR ROTOR NEAR THE AXIAL CENTRE OF THE ROTOR. THE GENERATOR WAS OPERATING AT 500 MW AND THE AVERAGE ROTOR WINDING TEMPERATURE AS DETERMINED FROM THE COPPER RESISTANCE MEASUREMENT WAS 55°C.